Improving Irrigation Water Use Efficiency in High Tunnel Agriculture

Grant Proposal

Claire Newcom

Massachusetts Academy of Math and Science

Advanced STEM with Scientific and Technical Writing

Instructor: Kevin Crowthers, Ph.D.

Worcester, MA. 01605

Executive Summary

The culmination of Climate change’s impact on the world, poor resource management, and rising global needs has resulted in a need to modify parts of our livelihoods. This project aims to collect rainwater from high tunnel structures for the purpose of better resource management. Modifications are to be made to the high tunnel cover to reduce water loss. The purpose of high tunnels is to extend the growing season, allowing for more crops to be produced (Gu, 2021), with the high tunnel covers used to trap in heat. High tunnels, and their abilities to produce more crops, are needed to feed the growing global population (United Nations, n.d.). While high tunnels are useful, there are issues related to water usage and water waste, as high tunnel covers are impermeable, resulting in a need for irrigation. In this project, rainwater is aimed being collected because it would be wasted off the high tunnel if not collected due to the impermeability of the tunnel covers. It is also being collected due to a growing need to reduce reliance on underground water resources (James, 2023), of which high tunnels often draw on as they are unable to use rainwater to water plants (Gu, 2021).

Keywords: rainwater, high tunnel cover, modified, collecting, high tunnel

Improving Irrigation Water Use Efficiency in High Tunnel Agriculture

Severe climatic conditions make it difficult for food to be produced, with intense and sudden changes in climatic conditions that can make a farmer's job more difficult. High tunnels are used to help extend the growing season to grow more food, but a lot of water is wasted because of the impermeable plastic coverings that block rain from reaching the ground. The goal of this project is to design a high tunnel cover that will reduce rainwater waste from a high tunnel.

Impact of Severe Climatic Conditions on Agriculture:

With the continual rise in carbon dioxide levels in the atmosphere around the globe, the average surface temperature of the Earth has risen (Lindsey & Dahlman, 2023). This has paved the way for more intense and frequent climatic events (Li et al., 2021; Climate Change Is Causing Global Hunger, n.d.). These intense climatic conditions have repercussions on crop yields and the greater agricultural industry, which is further predicted to have negative economic repercussions (De Winne & Peersman, 2021).

One type of the aforementioned intense disasters is droughts. Droughts have led to economic repercussions across Russia and Ukraine, where the reoccurring droughts have led to fluctuations in the prices of wheat and corn all over the globe (Banerjee et al., 2018). Another type of intense disaster that is impactful on the agricultural industry is tropical storms. High amounts of rainfall, caused by tropical storms, can lead to plants and soil washing away, decreasing the crop yield for the areas where these storms hit (Fletcher et al., 2018). Tropical storms and hurricanes can also contribute to storm surge and the contamination of freshwater resources with saltwater, impacting both humans and agriculture (Fletcher et al., 2018). Fluctuations in the amounts of water that could be present in an area over time can lead to inconsistencies in water usage when growing crops, which is an issue. Collecting and utilizing excess rainwater from periods of high rainfall could reduce the impacts of droughts, and reduce these inconsistencies. The effects of intense disasters on the economy through damage done to the agricultural industry will be significant, but the impacts of intense disasters on agriculture are also important to consider in relation to rising global populations.

Population Food Needs:

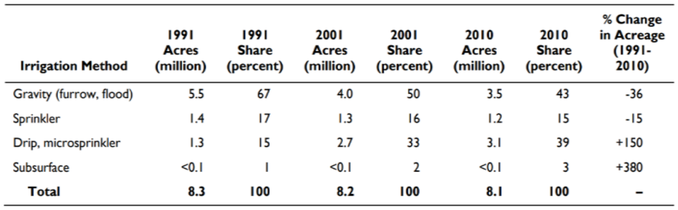
Around the world there is a need for better food resource management, and more readily available healthy food options (World Health Organization, 2019), and the agriculture industry will be one of the factors needing to adapt to meet this need. This need for better food resource management will continue to grow as the global population increases towards a projected global population of 9.8 billion people in 2050 (United Nations, n.d.). Though growing food has been made more difficult due to increased climatic disasters (*Climate Change Is Causing Global Hunger*, n.d.), more food will need to be made available in the future. Currently, there are farming practices, including the usage of high tunnels, that allow for more food to be produced, however, these farming practices are not always efficient in resource usage, highlighting an area for improvement.

High Tunnels:

High tunnels, or hoop houses, are used to extend the yearly growing season for at least 4-6 weeks (Gu, 2021), allowing for a greater amount of food to be produced. They are comprised of steel or plastic structures, on which a plastic covering lies (Gu, 2021). High tunnels provide protection to plants against UV radiation and cold and frost at a relatively low cost (Gu, 2021). The tunnels are impermeable and require other forms of irrigation besides rain (Gu, 2021). Usually, plants grown within high tunnels are watered through drip irrigation systems, small sprinkler systems, or hand watering in high tunnels (Majumdar, 2018), with water often sourced from underground water resources. The impermeability of the plastic covering leads to issues with water waste, as any rainwater that would generally soak into soil is unable to and just washes away.

Some crops typically grown under high tunnels include tomatoes, cucumbers, and strawberries (Supriya, 2021; *JSS Advantage - February 2010*, 2010; RFAgriculture, 2020; Gu, 2021), which all require large amounts of water for proper growth. One area where high tunnels can be used is California, as that is where tomatoes and strawberries are most commonly grown in the United States (Guan et al., 2018; USDA, 2020). Both tomatoes and strawberries require about 1-2 inches of water per week to grow properly (Cohrs, 2023; Lobo, 2023; Rhoades, 2021; *Growing Berries*, n.d.). Due to these plants being grown underneath high tunnels, even if California got enough water during the year, which this year it did at an average of 1.85 inches (*California Water Watch*, 2023), the plants would not receive any of it. The inability of water to pass through the high tunnels to assist in the irrigation of plants highlights an issue revolving around water waste and agricultural irrigation practices.

Drip Irrigation:



Irrigation Method	1991 Acres (million)	1991 Share (percent)	2001 Acres (million)	2001 Share (percent)	2010 Acres (million)	2010 Share (percent)	% Change in Acreage (1991-2010)
Gravity (furrow, flood)	5.5	67	4.0	50	3.5	43	-36
Sprinkler	1.4	17	1.3	16	1.2	15	-15
Drip, microsprinkler	1.3	15	2.7	33	3.1	39	+150
Subsurface	<0.1	1	<0.1	2	<0.1	3	+380
Total	**8.3**	**100**	**8.2**	**100**	**8.1**	**100**	**–**

Table 1. Trends in Irrigation Methods, 1991-2010. As of 2010, gravity irrigation methods were the most commonly used irrigation methods. Though drip irrigation and microsprinkler methods, which both save water, are becoming more common, there is still a significant portion of land irrigated by more wasteful gravity methods. Johnson, R., & Cody, B. A. (2015). California Agricultural Production and Irrigated Water Use (R44093). Congressional Research Service (CRS). https://crsreports.congress.gov/product/pdf/R/R44093.

In agriculture, drip irrigation systems are commonly used to increase water sustainability by giving only the necessary amount of water to plants (Deines et al., 2021; Chu, 2017). Drip irrigation systems decrease the amount of water lost from the soil from evaporation or drainage (Chu, 2017). With other irrigation methods, such as flood irrigation, water is commonly lost due to evaporation or drainage (Chu, 2017). Flood irrigation has been a common irrigation practice since ancient times (Chu, 2017), and it is still common in California, as seen in Table 1, though it has been decreasing in usage. Table 1 also shows an increase in the acreage where drip irrigation practices are employed, providing evidence of improvement.

The downside of drip irrigation is that it can be quite costly, which limits the ability for it to be used on a wider scale. The costs come mainly from the power system and pump used to keep constant pressure within the system to ensure that every plant gets water (Chu, 2017). They can also get clogged with soil or damaged by animals chewing on the pipes, which results in the damaged parts needing to be replaced, thereby increasing the cost (Bahr, 2022). The system itself, however, is beneficial to the environment and can help farmers in developing countries irrigate their crops with higher water efficiency (Chu, 2017).

Aquifers:

In many agricultural areas, water is drawn from aquifers for irrigation purposes, and this can lead to a multitude of problems involving water resource sustainability (James, 2023). For example, in California, water has been pumped out of aquifers to irrigate agricultural land for at least 20 years, and this has caused the subsequent depletion of waters within the aquifers (James, 2023). In dry years, reliance on these aquifers for irrigation is higher, and when this reliance stays high for a long time, the aquifers are eventually depleted of water and can collapse (James, 2023; Desert Research Institute, 2023). Aquifer depletion can also lead to subsidization, which is the gradual sinking of land, which can be a major problem for agriculture, infrastructure, and coastal areas that are at risk from flooding (Desert Research Institute, 2023). There is a need for a water management system that does not rely on aquifers to water crops.

Goal:

The goal for this project is to begin formulating a way of adapting high tunnels to better manage water resources. Using engineering principles and innovative designs, the aim of this project is to maximize the amount of water collected off a high tunnel structure.

Section II: Specific Aims

The overall aim of this project is to reduce the effect of droughts on agriculture by designing a high tunnel cover to reduce water loss to increase the amount of rainwater collected off a high tunnel structure. The expectation is that the proposed design will collect water with the aim of reducing water waste, allowing for greater water use efficiency.

The work proposed here will…

Specific Aim 1. Reduce water waste in high tunnel agriculture through specialized irrigation collection systems.

Specific Aim 2. Reduce the dependence of farmers using high tunnels on underground sources of water to reduce damage caused to aquifers.

Specific Aim 3. Reduce the effects of droughts on high tunnel agriculture by increasing water use efficiency in high tunnel agriculture.

The expected outcome of this work is that the proposed high tunnel cover design will increase water usage efficiency through reducing reliance on aquifers for high tunnel irrigation, as compared to the control, where there is a non-optimized cover.

Section III: Project Goals and Methodology

Relevance/Significance. This project is relevant to the field of agriculture, specifically the area of agriculture and irrigation where water for irrigation comes from beneath the ground, and to the need for a water resource management system that can reduce the effects of droughts through reducing water loss and increasing water use efficiency.

Innovation. In this project, the aim is to design a material for a high tunnel cover that reduces the splash rate of rainwater, with the intention of increasing the amount of rainwater that could be collected off a high tunnel. This is aimed to reduce the effects of droughts by increasing the amount of non-underground water available to use.

Methodology:

Specific Aim #1:

The objective is to reduce water waste for irrigation in high tunnel agriculture through a specialized cover design. Our approach is to optimize different aspects of a plastic cover, such as the surface of the cover having protrusions or other non-smooth surfaces, where the water that could be collected would then be made available for irrigation use. Our rationale for this approach is that the water that plants are unable to use due to being beneath the high tunnel will be wasted because plants are unable to access it, and only the water that reaches the gutters can be collected as splashing can occur, so a design that reduces splash will leave more water available.

Justification and Feasibility. According to a report by Johnson and Cody in 2015, California has the highest water use per acre compared to other states, with the majority of that water usage going towards irrigation. Though the area is relatively arid compared to eastern states (Johnson & Cody, 2015), water from rain is still present often wasted and washed out into the ocean (Kelly et al., 2023). Shouse and Naeve describe a method for a collecting water using gutters on a Quonset (curved shape) style high tunnel, and claim to collect about 900 gallons of water per half inch of rain on a 30 by 95 foot sized high tunnel. This rainwater would be wasted if not collected and can now be used to water plants underneath the high tunnel structure. For high water use crops, such as tomatoes or strawberries which need 1-2 inches of water per week (Cohrs, 2023; Lobo, 2023; Rhoades, 2021; *Growing Berries*, n.d.), even a half-inch of water makes a substantial dent in the amount of water needed for the plants to grow properly. Importantly, there was a lack of data presented to back up the claim of about 900 gallons of water per half inch of rain on the 30 by 95-foot-high tunnel, so some water could have been lost due to splashing that was not accounted for.

Summary of Preliminary Data. The preliminary data collected concerned different possible coverings for high tunnel structures, and the amount of water that splashed off the coverings when they were held taught over a Gothic, or peaked, style high tunnel. The aim of this test was to find the type of covering that had the least amount of splashing, as that covering would logically have the most amount of possible water that could be collected by gutters. This correlates to less water wasted, because if the water can be collected by the gutters, then it can be used, and the more water that can be collected means the least amount of water wasted. As seen in Figure 1, 3 mm polyethylene had the lowest splash rate, meaning that it is considered the most optimal out of all of the designs as is, but because there was still waste it could be improved upon so even less water is lost.

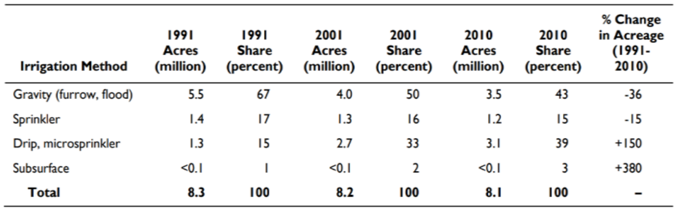
Expected Outcomes. The overall outcome of this aim is to reduce water wasted in irrigation practices by understanding how rainwater splash can be reduced, which would thereby increase the amount of water that can be collected. This knowledge will be used for developing a high tunnel cover design that will collect rainwater from a high tunnel, reducing water waste.

Potential Pitfalls and Alternative Strategies. We expect that there will be many possible components that could possibly be used, which will require extensive testing. An alternative strategy that may result in optimization may be looking at nature for ideas about collecting water. A secondary alternative strategy may include implementing both unique ideas, and concepts drawn from nature that could be used for collecting water.

Specific Aim #2:

The objective is to decrease reliance on underground sources of water for agriculture irrigation through improving high tunnel cover design. Our approach is to develop a high tunnel cover design to reduce rainwater loss, with the eventual goal of using rainwater for irrigation, reducing the amount of water needed from aquifers. Our rationale for this approach is that using rainwater for irrigation purposes would reduce the strain and reliance on aquifers as rainwater does not draw on aquifers.

Justification and Feasibility. In California, rainwater is commonly captured in reservoirs; however, these fill up quickly (Kelly et al., 2023). Rainwater is also commonly stored in aquifers, however, these are hard to get water to percolate to (Kelly et al., 2023). Even though some water is collected and stored, a lot of it ends up in the ocean because it was never collected in the first place (Kelly et al., 2023), which is not ideal as California is still in need of water in their aquifers. Agricultural irrigation does not help with the issue, as it accounts for roughly 40% to 60% of total water withdrawals (Johnson & Cody, 2015). The aquifers have suffered from decades of overuse, and even the extremely wet year that they have had has not been enough to refill the aquifers (James, 2023). Storing water can reduce the effects of droughts in the future, but collecting and storing more extra water safely is needed, especially to fill depleted underground water sources (Kelly et al., 2023).



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As seen in Table 1, as of 2010, gravitational irrigation methods accounted for the majority of irrigation methods used in California (Johnson & Cody, 2015). Using more conservative irrigation methods, such as drip irrigation, can reduce the water needed to grow crops, and saves water resources by reducing waste (Johnson & Cody, 2015). However, as drip irrigation in high tunnels draws from aquifers, the aquifers will still deplete over time, highlighting a need for a different water source.

It is relevant to create a specialized cover design that will aid in the collection of rainwater, as it will reduce the reliance on other irrigation sources.

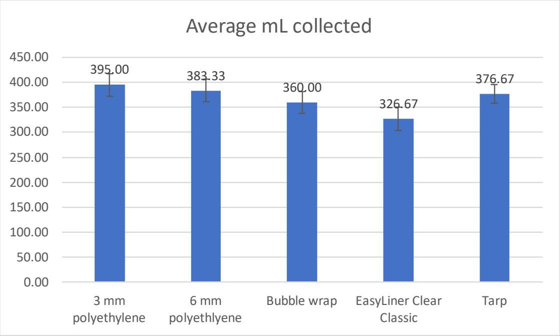

Figure 1. *Preliminary data showing the average mL of water collected, meaning what was not lost due to splashing when water fell onto a miniature, not to scale, high tunnel with various coverings. 500 mL fell onto the different coverings in each test (N = 3). In each test, the water was dropped from a height of 67.5 inches out of a bucket with a valve. The water was collected in a 14 by 13 by 2-inch container.*

Summary of Preliminary Data. In the preliminary testing, 5 different possible cover types were tested, with the intention of finding the cover that would allow for the most amount of water to be collected, because the most amount of water that can be collected will result in more water to be used for irrigation, which will reduce reliance on aquifers. As seen in Figure 1, a less apparently rigid material, the 3 mm polyethylene had the highest amount of water collected, whereas a more apparently rigid material, the EasyLiner Clear Classic, had the lowest amount of water collected. Because the 3mm polyethylene had the highest amount of water that was collected in the container, that would mean that it would have the most amount of water that could go towards watering plants. The 3mm polyethylene still had some water loss, which could be improved upon.

Expected Outcomes. The overall outcome of this aim is to develop a design for a high tunnel cover that will aid in the collection of rainwater. This knowledge will be used with the further intention of using this rainwater to water plants.

Potential Pitfalls and Alternative Strategies. We expect potential pitfalls to include difficulties in creating or determining the material. Alternative strategies for creating the material more easily include utilizing 3D printers, and utilizing other materials that are easily accessible.

Specific Aim #3:

The objective is to reduce the effects of droughts on agriculture by increasing water use efficiency through a reduction in water waste and using the resources available. Our approach is to break down the steps of collecting, storing, and distributing water, and looking at how water can be collected, then further looking at how to allow for the most amount of water to be collected. Our rationale for this approach is that by focusing on the collection of water, it can be optimized, allowing for storage and distribution to occur later. The collection of water would also increase water use efficiency as the water that would otherwise go unused is not wasted.

Justification and Feasibility. There are some irrigation systems that waste a lot of water, which is not ideal in droughts. One of these systems is called flood irrigation, and it is a type of surface irrigation that relies on gravity to function (Water Science School, 2018). With flood irrigation, there is often a lot of runoff water that is wasted (Water Science School, 2018), and it is difficult to control the amount of water released (Chu, 2017).

While flood irrigation systems are still used today, there are other irrigation systems that do not waste as much water, such as drip irrigation systems (Chu, 2017; Water Science School, 2018). There are many benefits and perks for using drip irrigation systems, as they apply water directly to the plant, reducing water waste, and they also can evenly distribute fertilizers (Water Science School, 2018).

Drip irrigation systems still need water to function, and that water needs to come from somewhere. In high tunnels, supplying water for irrigation purposes is necessary (Gu, 2021), and most of that water is supplied by aquifers (James, 2023), disregarding the resource of rainwater, accentuating a need.

Summary of Preliminary Data. In the preliminary testing, water loss due to splashing off a miniature high tunnel was measured using the final volume of water and subtracting from the initial volume of water. 500 mL of water was dropped onto the miniature high tunnel using a bucket, with a valve, that was elevated to a height of 67.5 inches. 5 different covers were tested and were chosen because they represented different high tunnel cover surfaces, for example, a raised surface or a smooth surface, that might have an impact on the water loss rate. Out of the tested covers, the 3mm polyethylene had the least average percentage of water loss, as seen in Figure 1. Figure 2 shows the distribution of the data, with the X's showing the average water collected. Both 3mm polyethylene and 6 mm polyethylene had wider distributions, but a more centralized median, whereas the bubble wrap, EasyLiner Clear Classic, and the tarp had median values that were in the upper half of the box. This provides evidence for an outlier in the bubble wrap, EasyLiner Clear Classic, and the tarp, as a higher median compared to the box means that most of the numbers were of greater value. However, even if an outlier measurement had not occurred, the EasyLiner Clear Classic, which was the most rigid material, still underperformed compared to the rest of the cover types, highlighting that the rigidity of the plastic may have an impact on how much water is lost. More water lost means a greater misuse of vital materials needed in a drought, meaning that an engineering design must implement findings related to lower water loss.

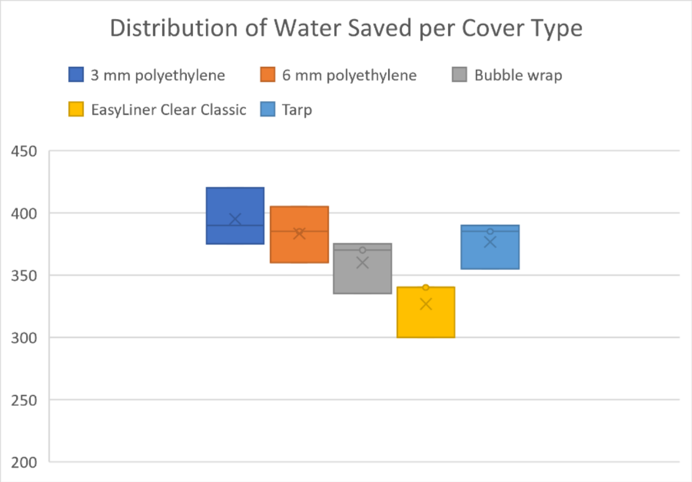

Figure 2. *Preliminary data showing the distribution of data for each of the 5 cover types (N=3). The water fell onto a miniature, not to scale, high tunnel model, and was lost due to splashing. In each run, 500 mL of water fell onto the different coverings. In each test, the water was dropped from a height of 67.5 inches out of a bucket with a valve. The water was collected in a 14 by 13 by 2-inch container.*

Expected Outcomes. The overall outcome of this aim is to use engineering design principles and then improve water collection to eventually lead to assistance in the mitigation of the effects of droughts. This knowledge will be used to begin reducing the effects of droughts.

Potential Pitfalls and Alternative Strategies. We expect that some potential pitfalls include difficulties with using water to test the covers and collection abilities. The tests are expected to be conducted outside, so it may be that air temperature influences the water being used. Some alternative strategies if this becomes an issue are recording temperature to look at possible correlations or using different initial water temperatures.

Section IV: Resources/Equipment

- Plastic sheet made out of PE plastic
- Bubble wrap
- EasyLiner Clear Classic
- Tarp
- PVC pipes
- Wooden boards
- Gutters (Plastic, metal, etc.)
- Buckets
- Water
- Water dispersion valve
- Watering can/spray nozzle/shower head
- Storage container
- Graduated cylinder(s)
- Ladder
- Stapler/staples
- (Possible) thermometer

Section V: Ethical Considerations

No humans or animals are to be tested on in this project

Section VI: Timeline

Phase 1: Background Research: Completed by Dec. 16

- Read 10 or more articles on droughts and high tunnels
- Research what others have accomplished; patent searches and competitor analysis

Phase 2: Initial Proof of Concept and Prototype development: Begins Nov. 12, ends Jan 7

- Develop design matrix

- Test plastic covers
- Begin designing further ideas

Phase 3: Prototype 2 Design and Testing: Begins Jan 8, ends Jan. 15

- Construct proof of concepts of designs
- Test proof of concepts of designs
- Make modifications to designs
- Test modified designs

Phase 4: Prototype 3 Design and Testing: Begins Jan. 16, ends February 3

- Make modifications to best design from Phase 3
- Test modified design
- Make further modifications
- Test modified design

Phase 5: Presentation: Begins Jan 21, ends February 14

- Develop poster presentation
- Practice for presentation

Section VIII: References

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